The Role of Storm Resuspension in Contaminant Transport in Marine Environments

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LONG-TERM GOAL

My goal within the Harbor Processes program is to develop an integrated resuspension-sorption model for the marine environment and apply it to investigate the roles of resuspension, transport, and sorption in the redistribution and loss of sediment-associated contaminants during storm events.

OBJECTIVES

The objectives of this project for FY99 have been to 1) investigate computationally efficient ways of representing sorption to and from suspended sediment that can be implemented at a time step comparable to the time step in time-dependent suspended sediment transport calculations; and 2) to characterize time scales associated with sediment transport events at sites on the continental shelf of varying wave climate.

APPROACH

My approach is to develop, test, and apply a physically based, coupled model of sediment suspension and sorption to investigate transport of sediment-associated contaminants in marine environments.

WORK COMPLETED

Model development during the past year has primarily focussed on exploring the range of possible methods for solving the radial sorption equation for a suspension of mixed particle sizes. Four approaches have been considered: 1) explicit numerical methods; 2) implicit numerical methods; 3) analytical solutions; 4) polynomial fits to numerical solutions. The goal of this exploration is to identify the most efficient method that permits sorption to be calculated at a time step compatible with the time step of the suspended sediment transport calculations. An explicit numerical solution had been developed prior to this study. We have considered analytical solutions, polynomial approximations, and implicit numerical solutions in addition to explicit solutions this year.

High quality bottom boundary layer flow and suspended sediment data are available for 3 sites on the California shelf with comparable sediment (silt) at mid-shelf depths but significantly different wave climates. Although only one of the sites is contaminated, the three sites provide an opportunity to investigate transport, sorption potential and effects of flocculation under a range of flow conditions. Wave climate, transport potential, and duration of transport events have been compared for the three sites.

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RESULTS

Methods for solving the radial diffusion equation

Explicit methods for solving the radial diffusion/sorption problem (Wu and Gschwend, 1983; Wiberg and Harris, submitted) impose strict limits on the relative spatial and time steps allowable for stability. These limits are particularly restrictive for calculations of sorption from small particles and over long time periods. Two approximate analytical solutions to the equation describing diffusion from a sphere with a mass-conserving boundary condition (i.e., total mass in fluid and sediment must remain constant) are available for the special case of a single particle size (Crank, 1975). However, natural suspensions comprise a range of sizes that affect the time history of sorbed concentrations in the particles and fluid. Implicit numerical methods offer solutions with less restrictive conditions on time steps than explicit solutions. However, the mass conserving boundary condition is more difficult to implement in implicit methods. Two approaches to specifying this condition (one integral, the other as a surface flux) are currently being evaluated in an implicit solution.

An alternative approach is to calculate explicit solutions over a range of conditions (concentrations, partition coefficients, and size distributions) and characterize the results through polynomial regressions. This approach is useful only if the coefficients in such regressions follow some regular trend that allows intermediate cases to be treated through interpolation of coefficients for cases within the range of, but not identical to, cases for which the explicit solutions were determined. We have expanded an analytical solution valid for short times into an infinite series to identify the structure of the polynomial equation that could be expected to best fit the sorption time histories. This process also generated polynomial coefficients for the regression equation that are consistent with the analytical solution. A regression of the first 6 terms of the resulting equation against an analytical time series yielded coefficients almost identical to those of the corresponding terms in the infinite series. However, these coefficients had be fit to a long time series for accurate results – fitting only the initial portion of the time series leads to divergent time histories as the relationship is extrapolated to longer times. Our next task is to fit sorption curves calculated using a numerical model for a range of conditions and determining whether the variation of coefficients is systematic. If so, then we have the possibility of parameterizing sorption in the suspended sediment calculations.

Comparison of transport events at sites with differing wave climate

Large field studies of bottom boundary layer flow and sediment transport have been conducted at three sites on the California continental shelf: the STRESS study of the Russian River shelf; the USGS study of the Palos Verdes shelf; and the STRATAFORM study of the Eel River shelf. Each of these studies included at least one winter storm season of current, wave, suspended sediment, and bed property measurements at more than one location on the shelf. Each site includes a mid-shelf silt deposit with similar sediment characteristics. However, the wave climate at each site differs significantly, with very energetic conditions on the Eel shelf and much lower wave conditions on the Palos Verdes shelf (Figure 1). The availability of flow and sediment transport data from mid-shelf depths at each site provides an excellent opportunity for comparative investigations of sediment transport and the roles of processes such as particle flocculation and bed consolidation that are potentially important for transport of sediment-associated contaminants.

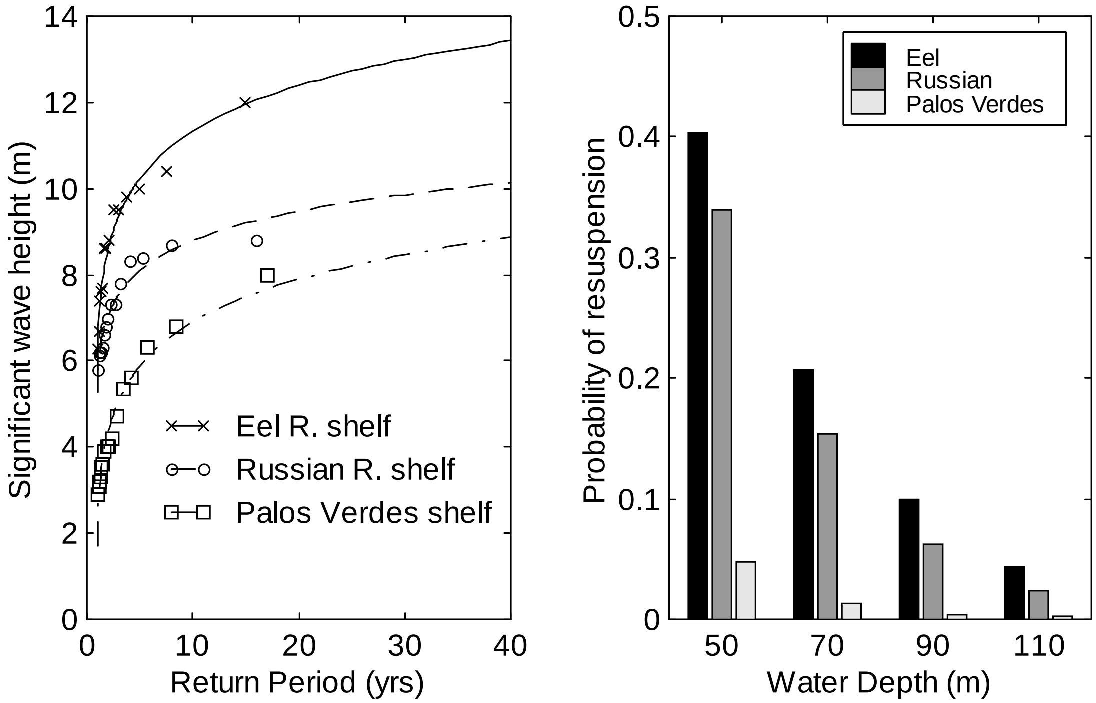

Figure 1. Comparison of a) annual maximum wave height and b) probability of resuspension across the shelf for the Eel, Russian and Palos Verdes, California shelves based on 17 years of wave data from NOAA buoy sites 46022, 46013, and 46025, respectively.

An important control on contaminant transport in marine environments is the relative time scales for sorption, resuspension, and flocculation. Sorption time scales depend on sediment concentration, contaminant partitioning between fluid and solid phases, and sediment size. For natural size distributions, equilibrium sorption time scales can range from hours to weeks, particularly if particles flocculate in suspension. Size fractions with sorption time scales shorter than the duration of resuspension events will approach equilibrium concentrations whereas size fractions with much longer time scales may experience minimal desorption during transport events. Durations of resuspension events can be estimated from time series of bottom wave velocities calculated from NOAA wave data measured at the three sites beginning in the early 1980s. A threshold wave velocity for resuspension is required to identify transport events. A threshold value of maximum significant bottom wave velocity of 14 cm/s corresponds to observed conditions for resuspension at mid-shelf depths all three sites and was used in this analysis. The resulting distributions of the duration of resuspension events at a water depth of 60 m for the three California shelf sites are shown in Figure 2.

IMPACT/APPLICATION

The approaches being used here for comparing sediment transport potential at various shelf settings provide useful measures of important transport characteristics for a range of shelf process studies.

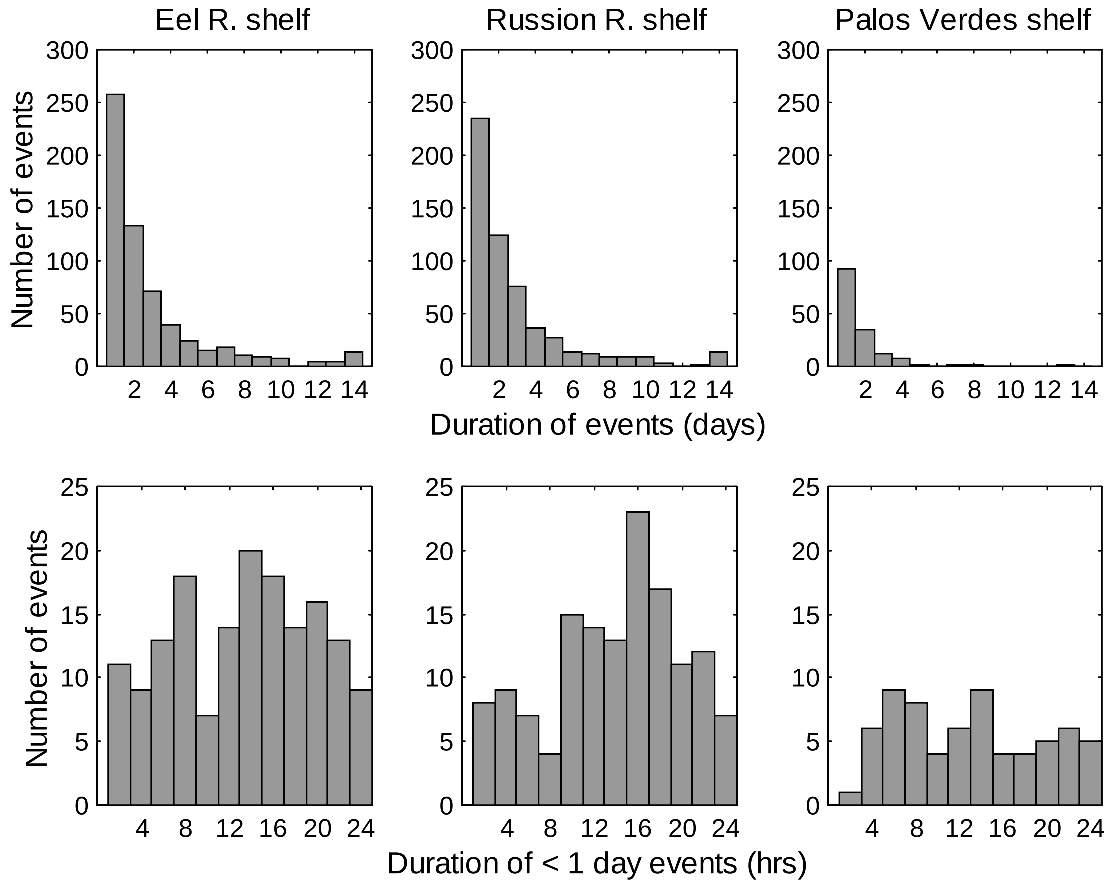

Figure 2. Comparison of distributions of sediment transport event duration at a water depth of 60 m for 3 sites on the California continental shelf based on 17-year records of wave conditions recorded by NOAA wave buoys and a threshold bottom wave velocity of 14 cm/s.

RELATED PROJECTS

The shelf sediment transport model being used in this study was originally developed in the STRESS program and has been modified and tested during the STRATAFORM program. Ongoing model-related work in STRATAFORM includes adding bed consolidation and flocculation to the model, both of which are potentially important for transport of sediment-associated contaminant transport during resuspension events.

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